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HUMAN SUPERVISION OF MULTIPLE AUTONOMOUS VEHICLES

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Interim Report

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To support the vision of a system that enables a single operator to control multiple next-generation unmanned air vehicles from a single workstation, a new interface paradigm is required. The interface must consider different types and levels of human-automation interactions. For instance, the interaction will move from one of human-directed mode selection and activation to more dynamic, bilateral and mixed-initiative human-automation decision-making, collaboration, negotiation, even conflict resolution across a range of situations. This project involved several threads of research to start examining human-automation interaction issues. One research thread focused on determining the appropriate level of automation for tasks envisioned for supervisory control of multiple UASs. Another thread involved the design and evaluation of a temporal interface for support of multi-UAS control and interaction with automation. Finally, a third research thread involved support for other projects that informed future operator-automation interfaces. This report provides a brief review of these research threads.

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1. ABSTRACT

To support the vision of a system that enables a single operator to control multiple next-generation unmanned air vehicles from a single workstation, a new interface paradigm is required. The interface must consider different types and levels of human-automation interactions. For instance, the interaction will move from one of human-directed mode selection and activation to more dynamic, bilateral and mixed-initiative human-automation decision-making, collaboration, negotiation, even conflict resolution across a range of situations. This project involved several threads of research to start examining human-automation interaction issues. One research thread focused on determining the appropriate level of automation for tasks envisioned for supervisory control of multiple UASs. Another thread involved the design and evaluation of a temporal interface for support of multi-UAS control and interaction with automation. Finally, a third research thread involved support for other projects that informed future operator-automation interfaces. This report provides a brief review of these research threads.

2. INTRODUCTION

This is the final report for Task Order 18, entitled "Human Supervision of Multiple Autonomous Vehicles," under the Warfighter Interface Research & Technology Operations (WIRTO) contract (FA8650-08-D-6801) between the Air Force Research Laboratory (AFRL) 711th HPW and Ball Aerospace & Technologies Corporation (BATC). This task supports research conducted by the Supervisory Control and Cognition Branch (RHCI), which involves the evaluation of operator-automation interfaces in support of envisioned future mission requirements to have a single operator supervise multiple autonomous vehicles. The major studies are described in this report, which is the final report for this task. The goals of this project include designing intuitive methods of interacting/coordinating with complex automation, techniques that improve operator awareness of automation mode and rationale for decisions made, appropriate applications of levels of automation to multi-vehicle control interfaces, evaluation of specific automation aids, and automation architectures that improve human-automation cooperation.

The period of performance was from 16 September 2008 to 22 March 2013. During this period, a number of studies were completed, and work on a few others was started. For experiments still in progress, support will continue in the follow-on Task Order 49.

Summaries of the major studies are provided in the following section. For additional information, the reader is referred to the References section of this report.

3. STUDIES SUPPORTED

Many current unmanned air vehicle systems (UASs) require that operators have the capability to manually fly the vehicle and activate state changes (i.e., direct tele-operation). Thus, human-automation interaction has been limited to simple commands such as autopilot functionality. With newer, highly automated UAS under development, the operator’s role is becoming more supervisory in nature, monitoring the environment or situation along with the automated activation of programmed events, and managing changes to the automated mission plan. Though far more advanced than autopilot modes, the automation function remains relatively rigid in application and restricted in scope to specific tasks like route preplanning. Operator interfaces must also take into account issues associated with automation management including vigilance, automation brittleness, visibility, feedback, etc.

Continuing this trend beyond the current state-of-the-art, there is a requirement for a new interface paradigm for controlling multiple next-generation UASs from a single workstation. Envisioning “intelligent” unmanned systems will have the ability to make higher-order assessments and decisions independent of operator input and pre-defined mission plans. Here, the automation capability affords a vastly different type and level of human-automation interactions. The interaction will move from one of human-directed mode selection and activation to more dynamic, bilateral and mixed-initiative human-automation decision-making, collaboration, negotiation, even conflict resolution across a range of situations. Therefore, there was a requirement to examine human-automation interaction issues and efforts completed in the project are described in this report.

This project involved several threads of research. One research thread focused on determining the appropriate level of automation for tasks envisioned for supervisory control of multiple UASs. Another thread involved the design and evaluation of a temporal interface for support of multi-UAS control and interaction with automation. Finally, a third research thread involved support for other projects. This included contracted efforts that informed future operator-automation interfaces. Each of these research threads is described in more detail below.

3.1 Determine Task Autonomy Level

3.1.1 Autonomy Level to Support Camera View Transition

The first evaluation conducted under this project was actually initiated under a previous RHCI effort to examine novel interfaces for multi-UAS control. The interface under evaluation addressed the requirement for an operator in a multi-UAS application to switch attention between vehicles and their respective camera views. An automated aid was designed that transitions between camera views. Instead of discretely switching from the camera view for one UAS to the camera view for another, a transition format was presented. With this format, the camera imagery seamlessly fades into a synthetic imagery correlate of the real video image and then uses a "fly-out, fly-in" metaphor over several seconds, finishing with a transition back from synthetic to real video imagery at the new camera viewpoint (illustrated in Figure 1).

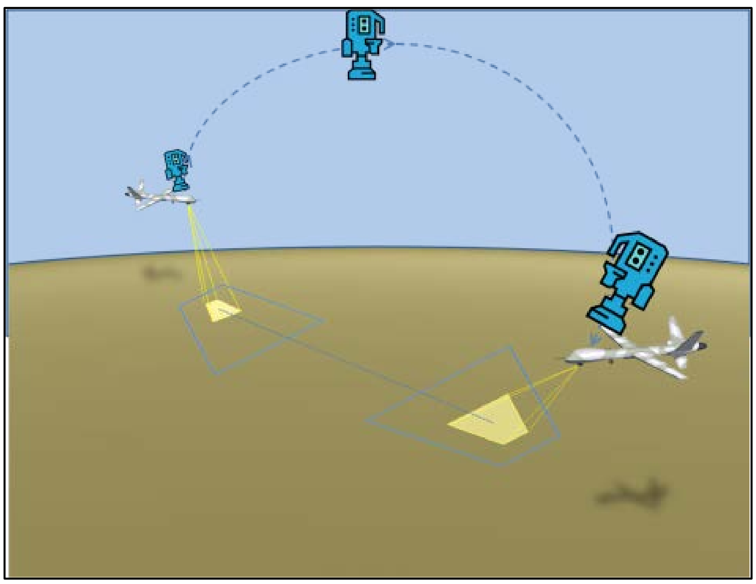

Figure 1. Conceptual Illustration of Transition Display Aid to Acquire Situation Awareness in New Camera View

Three conditions for switching camera views of two geographically separated UASs were evaluated in a multi-UAS simulation: 1) Discrete Switch: the camera view switched immediately to the new camera view; 2) Semi-Automatic: participants viewed a 0.5 s, "fly-out" from the first camera view to approximately 12,000 ft. over the new UAS (i.e., "global view"). At this altitude, the operator then could slew this "virtual camera" with the joystick to change the viewpoint. Selection of a joystick button initiated the "fly-in" transition which lasted approximately 5 s; and 3) Automatic: participants viewed a totally automatic transition format consisting of 0.5 s "fly-out," 2.0 s at the global view, and 5 s "fly-in." It was hypothesized that the Semi-Automatic and Automatic Conditions, despite delaying the new camera view several seconds, would result in

improved camera movement decisions/task performance because the view during the transition would afford participants better situation awareness of the area surrounding the second UAS. A second objective was to examine performance when the operator controlled when and where the “fly-in” segment of the semi-continuous transition began (Semi-Automatic Condition) compared to the full Automatic Condition. Participants may be able to locate a target faster in the second UAS’s camera view with the Semi- Automatic Condition, based on the assumption that searching for major landmarks is easier at a higher altitude.

The results from this experiment provided further support that an automated aid that presents a format which transitions from one camera view to a different camera view can improve decision making in regards to moving the camera to complete the task with the new camera view. The present data also suggest that the aid’s design should not be totally automated and instead allow the operator to control the global view segment of the transition (slewing the camera and initiating the fly-in segment). However, follow-on research is recommended to further explore the level of automation for this aid. It may be that similar performance advantages can be realized by lengthening the time spent in the global view for the Automated Condition. Additionally, the value of operator control of parameters needs to be determined for several transition segments and a variety of camera view transition applications. Further information is available in conference papers and a technical report (References 1-3).

3.1.2 Task Autonomy Level Evaluations

A series of experiments were conducted utilizing the Adaptive Levels of Autonomy (ALOA) multi-UAS simulation (developed by OR Concepts Applied; Reference 4) to determine the optimal level of automation (LOA) for mission related tasks. With the ALOA simulation, the LOA of several tasks can be systematically manipulated. The first experiment conducted with the ALOA simulation served as a checkout of the simulations functionality (Reference 5). Performance on routing tasks under three LOAs was evaluated as a function of the number of vehicles being supervised (one versus three). The results showed that participants took longer to complete the routing task when automation was high due to the time they spent verifying the accuracy of the imperfect decision aid. These results show the importance of designing an interface that provides an efficient method for interacting with the automation and communicating the automation’s rationale, especially under high automation levels.

Next an experiment was conducted that examined in more detail the optimal LOA for two primary tasks envisioned for multi-UAS control: allocation of tasks to UASs and re-routing of UASs (Reference 6). In the multi-UAS ALOA simulation environment utilized, these two task types were accomplished, in tandem, several times during each mission. After each trigger event (new imaging tasks), participants first assigned the new tasks across UASs, and then re-routed the vehicles to support the new allocation. Both “low” and “high” LOAs were evaluated for each task type (see Figure 2). The low LOAs required more manual selections to be made, whereas in the high LOAs, many steps were automated. A second objective was to determine whether the LOA of

one task impacts performance of the other mission tasks and whether there is an advantage for using similar LOAs (see Figure 2) across the two tandem tasks. Finally, the reliability of the router task was manipulated to examine the impact of imperfect automation in this supervisory control environment.

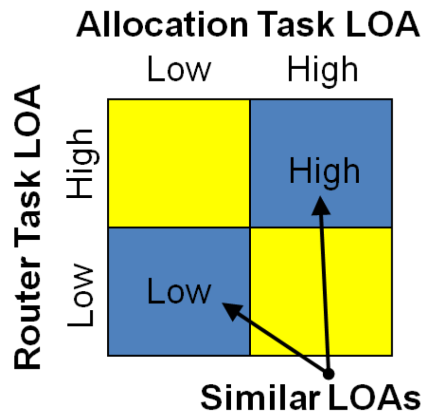

Figure 2. Experimental Design: Two Levels of Automation (LOAs) Were Examined for Allocation and Router Tasks

The results of this experiment supported the general notion that automation transference can occur - the automation level of one task can affect the performance of another task performed in the mission. Specifically, average task completion time was faster on each of the two sequential tasks (allocation and router) when the LOA was similar across these tasks versus mixed (mixed: one task highly automated and the other task with less automation). Moreover, the results suggest that manipulation of the LOA on these two tasks can affect performance on other types of tasks in the mission. This performance improvement was evident in the image analysis task, the task that occurred most frequently in the mission, and most likely reflects the benefits of high automation in allowing the participants more time to monitor mission progression and promptly attend to the image analysis tasks. Although these results demonstrate automation level transference across sequential tasks in a high-fidelity multi-UAS simulation environment, generalization of these results is limited because the participants in this study reported relatively low workload. Accordingly, a follow-on experiment was conducted to replicate this previous study with an increased task load. Besides increasing the frequency of some task types, there were changes in some of the tasks, to make them more cognitively difficult and increase operator workload. It is hypothesized that an automation transference effect will be more evident, compared to the earlier experiment, since automation can have a greater impact across tasks when workload is higher.

The results from this follow-on experiment (Reference 7) provided further evidence of mode errors in which the operator's actions are based on a false assumption of the automation's configuration. Performance was higher with the Similar LOAs than with the Mixed LOAs across several tasks suggesting that mode awareness is improved when both sequential tasks are at a similar LOA. Fine-grained variations of LOAs across tasks within a mission may negatively affect the operator's

knowledge and understanding of what automation configuration is in effect at any state or point in the mission. Thus, decreased mode awareness caused by detailed LOA adjustments within a mission could negate the benefits of applying automation in an attempt to reduce workload. The impact of LOAs is even more difficult to predict considering the number and variety of closely-coupled tasks involved in a complex application environment, such as multi-UAS supervisory control.

Another interesting result from this experiment pertained to the manipulation of the reliability of the router task. The data suggest that participants became complacent with the higher LOA (for instance, missing a router error that was presented after a series of trials with reliable automation). Performance was better with the low router reliability with the low LOA level, providing further evidence that when participants are more engaged in task completion, the automation's reliability has less of an influence on performance. The results in general indicated the need for further research to better quantify the cost-benefit trade-off of automation with imperfect reliability. In response, a follow-on experiment was conducted which essentially replicated the experiment (Reference 7), but extends the protocol by: 1) manipulating the automation's reliability level for both primary tasks (allocation and router), instead of just the router task; and 2) changing the router task in an attempt to increase its cognitive difficulty: participates were required to inspect the route on the map to determine its appropriateness, rather than just confirm routing parameters. The results provided further evidence that the autonomy level of one task can influence the performance of other tasks and that further research is needed that systematically examines task LOA and automation reliability to better understand the factors that influence automation level transference (Reference 8).

In future research, one objective might be to determine how the degree to which the LOAs differ influences participants' mode awareness and whether performance is improved when LOAs are consistently applied across the mission. This begs several questions. Would there be mode awareness issues if only certain intermediate LOAs were employed, in contrast to a large difference between LOAs? Additionally, what "equates" LOAs across task types? Would a LOA that provides alternative choices for an allocation task be equal to a LOA providing alternatives for a router task? There is a need for research evaluating multiple unique combinations of LOAs across a variety of representative tasks to identify the best suite. Indeed, increasing the LOA of a task to relieve an overloaded operator or decreasing the LOA to mitigate complacency effects may have an overall negative effect if it leads to increased mode confusion.

Besides understanding how LOA variations across the mission affects performance, the possibility of the automation level influencing the participants' general state (e.g., arousal) needs to be examined. It may also be that there is a complex interaction of factors (arousal, alerting, motivation, personality, etc.) determining the automation level's influence on participants' cognitive strategy and interface manipulation. Along with examining these transient states, an assessment of participants' trust in the automation is also paramount.

Research with the ALOA simulation was continued, to better understand what psychological factors mediate effective automation reliance and automation transference. An experiment was conducted that employed a similar research paradigm to that described above. Additionally, several instruments were also administered before the conduct of experimental trials to measure individual differences (e.g., 40 Mini-Marker Personality Index, Attentional Control Survey, Desirability of Control Scale, propensity to trust measure and the short version of the Dundee Stress State Questionnaire). The performance data results were similar to those found in earlier studies. Of particular interest were the results pertaining to the individual characteristic data. The results were encouraging in that many statistically significant results were obtained with these measures, despite the small sample size (n=12). Specifically, the results showed that individual difference data can indeed vary as a function of automation configuration (Reference 9). The results also highlight the complex interplay between personality factors, task type, and automation level. For instance, many of the measures co-varied with performance on specific tasks. In fact, one or more individual measures varied with performance on four of the task types. Most of the significant relationships were associated with participants' Emotion and Extraversion. However, all five personality traits were associated with at least one measure of a task or other measure (e.g., perceived workload or stress). However, as has been found earlier by Szalma and Taylor (Reference 10), the pattern of the relationships between individual differences and dependent variables varies across tasks and LOAs. As an example, ALOA participants with high Emotion performed the router task more accurately, regardless of LOA. However, these same participants performed the allocation task more accurately, but only when its LOA was high. Another example is that participants with high Emotion performed the allocation task better in terms of task completion time (low LOA only) and task accuracy (high LOA only). Further research examining individual differences in supervisory control environments is needed to better understand the role of automation support and how best to design operator interfaces that support appropriate automation reliance.

3.1.3 Adaptive Autonomy Evaluations

Given the dynamic nature of UAS missions, another approach for applying automation to help single operator control of multi-UASs is to employ adaptive automation, whereby the system flexibly allocates tasks between the operator and the automation in the context of the work environment. In this manner, the number of tasks automated, as well as their degree of automation, may vary at any given time with the goal of optimizing the tradeoff of operator involvement and workload. Several types of triggers have been identified to help determine when the operator will benefit from increased automation: in response to critical events, operator performance, operator physiology, models of operator cognition, and hybrid methods that combine one or more of the previous methods (Reference 11).

This project supported several experiments examining performance-based adaptive automation. In these evaluations, as operator task performance in the ALOA simulation degrades under increased workload/cognitive demands, higher LOAs were applied for one or more tasks. Otherwise, the

operator will be kept more in-the-loop for task completion to avoid common automation-induced problems (e.g., complacency).

Evaluations of adaptive automation in support of UAS control have been limited. The objectives of the studies conducted with the ALOA simulation are unique in that performance across multiple tasks is considered in determining when to adapt the automation. Additionally, the specific parameters employed in the algorithm driving the adaptive control scheme were examined. In the first evaluation addressing this topic (Reference 12), an adaptive condition (LOA adapted as a function of performance on five types of tasks) was compared to a static condition (where the LOA remained constant throughout the trials). In both conditions, the LOA pertained to the image analysis task. The results showed that performance-based adaptation of the image task autonomy level improved performance on the image task, as well as other task types. Additionally, participants preferred the adaptive automation condition and felt is reduced their cognitive workload and aided performance. Another result prompted the next experiment—changes across trials to increase the LOA outnumbered changes to decrease LOA. Examination of the data suggests that performance at a high LOA tends to be better (as it benefits from the automation) making it more difficult to meet threshold requirements to decrease the LOA. As a result, the adaptive algorithm tends to keep participants at a higher LOA where automation-induced problems (e.g., complacency) are more likely. Hence, it was decided to conduct an experiment with an asymmetrical adaptation scheme such that the algorithm's parameters were set so that it was easier to meet criteria to decrease LOA, compared to increasing LOA.

The results of this experiment comparing an adaptive control scheme with the asymmetrical parameters with the static (control) condition showed that performance-based adaptation of the autonomy level for the image analysis task improved both the speed and accuracy of performance on the image analysis task (Reference 13). Also, the new asymmetrical algorithm helped keep participants at a lower autonomy level where automation-induced problems are less likely.

In both of these performance-based adaptive automation studies conducted under this project, the results showed considerable variability in the number and timing of LOA changes within and across participants, indicating a need to further explore the utility of this method to balance workload between automation and the operator. Thus, another experiment was initiated to explore whether results to date reflect an attentional benefit from having the image task autonomy level change during trials. In other words, it may be that performance was improved in the adaptive condition, compared to the static condition, simply because the LOA of the image analysis task changed during the course of the trial – not that it changed in respect to performance.

In this experiment, a between-subject design was employed (Reference 14). For one participant group, the image analysis task LOA adapted according to the performance-based asymmetrical algorithm parameters employed in the previous study. For the other group, changes to the task's LOA were not tied to task performance, but rather changed as a function of time elapsed and at the frequency recorded during an earlier performance-based adaptive study. Data from 24 participants

were collected and the results indicated that performance did not significantly differ between the two groups. However, there were significantly more autonomy level changes in the performance-based adaptive group. A follow-on study utilizing a yoked-subject design is recommended (Reference 14) to better evaluate the potential attention-based benefit of LOA changes.

3.1.4 Adaptable Autonomy Evaluations

Another alternative to adaptive automation for re-balancing human-automation involvement in task completion is adaptable automation, whereby the operator controls task LOA. Using a similar experimental protocol with the ALOA simulation, a within-subjects design was conducted with some trials employing a performance-based adaptive control scheme (described earlier) and other trials having an adaptable control scheme in which participants could change the LOA of the image analysis task at any time during the trial by making selections on a window of the testbed (Reference 15). The results showed that mean performance on a different task, a change detection task, was slightly better with the adaptable condition compared to performance on it under the performance-based adaptive condition. This result suggests that the act of delegating LOAs itself may serve to better keep the operator in-the-loop and alert to unexpected stimuli. It is important to note, though, that the cognitive overhead of delegating LOAs in any adaptive system is removed from the decision-making process. In this respect, adaptable automation can have a performance cost, as there is workload involved in managing task LOA. This study's results supported this notion, as mean time to complete the image analysis task was slightly longer with the adaptable condition compared to the adaptive.

Data on the experimental participants' personality were also recorded in this experiment comparing adaptable and (performance-based) adaptive automation. The results showed a very strong correlation between extraversion and autonomy level choice for the image analysis task: highly extraverted participants chose the highest level of autonomy, which only required a response if they wanted to veto the automation's recommendation. In contrast, less extraverted participants chose a level of automation (medium) that required the operator's consent before acting (Reference 15).

Finally, while not a focus of this project, support was provided to an Air Force Headquarters funded effort to explore a specific application of an adaptable automation approach whereby an operator can flexibly change control modes ranging from low-levels of automation (manual, hands on throttle and stick) to high-level "plays" in which a verbal command initiates planning for a series of automated tasks. Support first involved conducting a literature search and operator interviews to identify candidate applications of automation in future UAS operations and specifically high-level plays that might be useful (Reference 16). Next, design specifications were determined for the display and control interfaces that support this multi-level delegation control concept. The design was then instantiated into a prototype computer simulation, with assistance with respect to the speech recognition component (Reference 17). The research stage involved the conduct of experimental sessions with storyboards and the demonstration simulation in order to

collect feedback from UAS operators on the usefulness of the "Flexible Levels of Execution-Interface Technologies" (FLEX-IT) concept for future UAS operations, as well as the usability of the display symbology and related controls and procedures. Ratings and comments from the nineteen UAS operators indicated that the FLEX-IT approach for adaptable automation is indeed promising in terms of providing intuitive methods to interact with automation as well as seamless transition back and forth between control levels (Reference 18). This involves mechanisms by which the pilot can make changes, navigate back and forth between control levels, take control and then give it back to the automation, all within the shared understanding of "what's going on." The approach also provides an ability to quickly tailor the automation's actions, as well as an option for direct manipulation inputs that assist in designating spatial locations.

To examine this multi-level control architecture for adaptable automation further, the design interface concept was expanded for multi-UAS test scenarios. This also involved the checkout of modifications made to the concept demonstrator as well as the conduct of a usability evaluation in which participants employed the multi-level control architecture during ninety minute sessions. Data included comments recorded with a think-aloud paradigm and questionnaire responses. The results indicated that this adaptable pilot-automation interface for multi-UAS control is promising. However, the findings reflecting perspectives from both pilot and gamer participants indicated that improvements are needed to enhance the interface's flexibility and usability (Reference 19).

A smaller scale experiment (Reference 20) was also designed and conducted to quantify how long it takes to use an intermediate level of control to specify maneuvers to be performed in the near future. With this novel control mode, the stick and throttle are remapped to translate the operator's inputs in azimuth and elevation changes to a directed flight path. This mode is referred to as the "noodle," as it presented a flexible line segment resembling a bendable noodle emerging from the nose of an UAS symbol on the map display. The quantitative data collected compliments the qualitative data collected in earlier studies (References 18 and 19) indicating this control mode for visualizing and commanding near-term future path is a definite candidate for future multi-UAS control. For example, the data demonstrates how the future flight path can be constructed very quickly (typically less than a minute). Comparing these data with an estimate of time to hypothetically fly the paths suggests a 90% attentional time savings for typical operations. Thus, the ability to easily set the complex flight path of one vehicle should allow more time to be focused on other vehicles, enhancing supervisory control of multiple UASs.

3.2 Design/Evaluate Novel Operator-Automation Interfaces

A second research thread addressed in this project involved the design and evaluation of novel interfaces for support of multi-UAS control and interaction with automation. Supervisory control of multiple UASs will require an operator to be simultaneously aware of the status of multiple vehicles, including their ability to meet any temporal constraints imposed by any cooperative

missions. A temporal interface may be useful for providing time-based information needed for multi-UAS supervisory control in addition to a map-based display and other status indicators. The vision for such an interface is to capture critical information in a single window relevant to the multiple vehicles being supervised, along with the missions they are performing and also provide control functionality such that selections in the *same* window will enable the operator to make inputs to automated sub-systems.

3.2.1 Evaluation of Temporal Interface Design Approaches

Unfortunately, there is a dearth of research or design guidelines related to temporal interfaces. For instance, one of many questions is how the display should be oriented. While a horizontal orientation is typically used in Gantt charts, a vertical orientation might be useful as a scan from left to right could provide more efficient retrieval of the status of all vehicles for a specific time slice. This may also help coordinate multiple vehicles across time. To address questions like these, support was provided in the functional design of a part-task testbed to be used in evaluations of candidate display formats. This testbed enables the evaluation of a variety of media (e.g., PowerPoint slides and movie clips) and provides the experimenter with numerous options to specify the duration of the format presentations, the content and viewing duration of questions designed to measure ability to retrieve information from the candidate formats, the mechanism by which the participants make responses, and how the data are recorded. With this new tool, several issues related to the design of the temporal format were rapidly evaluated without the expense of instantiating the format with software code.

In respect to the question of how the temporal format should be oriented, the results of an experiment conducted indicated that subjects' performance (response time and accuracy) did not significantly differ between the two orientation conditions (Reference 21). However, the majority of subjective ratings were in favor of the horizontal view. There were, however, certain tasks or situations identified that would benefit from a vertical orientation. Thus, research evaluating whether it is beneficial to provide operators the option to tailor a temporal format's orientation for a particular mission or task is needed.

An example of the use of the testbed to evaluate dynamic formats involved evaluating alternatives to portray the passage of time (Reference 22). Specifically, participants viewed two methods, each at two speeds of movement. In one method, the timeline moved from right-to-left, in respect to a stationary current-time vertical bar. In the other method, the timeline was fixed, and the current-time vertical bar moved from left to right. During the trials, participants watched the videos, answering questions requiring information retrieval. The results indicated that performance was best with the moving timeline condition at the faster movement speed, particularly on questions requiring planning decisions. Participants' subjective data were aligned with the performance data. The results suggest that it may be easier to retrieve information and judge the temporal relationship of events indicated with symbology elements when there is an apparent visual flow of the timeline symbology in respect to the fixed, stationary frame of the display window.

Use of this testbed to evaluate candidate formats and related design issues provided useful information for the design of a temporal display for multi-UAS control. However, such results are limited, for instance, because the participants' only task was to retrieve information from the temporal interface to answer questions. For multi-vehicle control, operators will be required to switch attention across multiple tasks, some employing the temporal format and some with other interfaces in the control station (e.g., communications and imagery inspection). Thus, a temporal interface that is dynamic and used in conjunction with a high-fidelity simulation of the entire task environment is required so that the experimental participant's workload represents the future vision of multi-vehicle supervisory control applications.

3.2.2 Prototype Temporal Interface for Multiple Vehicles Supporting Surveillance Mission

Research focus next turned to participating in the design of a temporal display to be instantiated in software and integrated into a high-fidelity multi-UAS simulation. Developing a dynamic temporal interface required several design considerations and decisions with respect to the required temporal data structures in order for the product to support the changing realities inherent in a multiple vehicle control system. Choices in how temporal information is stored, updated, and manipulated impacts the utility of the temporal interface and how the operator will be aware and interact with temporal information (Reference 23). An initial temporal interface prototype was developed and integrated into a modified version of the RHCI's Vigilant Spirit Control Station multi-unmanned vehicle simulation (Figure 3).

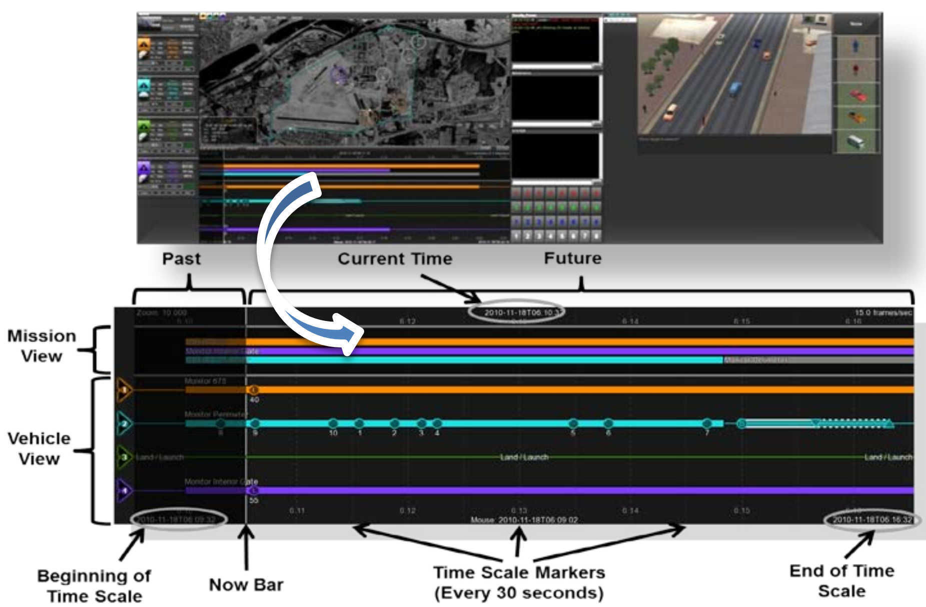

Figure 3. Prototype Timeline Interface Integrated into Vigilant Spirit Control Station

Horizontal bars at the top of the window provided information pertaining to the surveillance missions to be performed by the unmanned vehicles. In the lower portion, four color-coded

horizontal bars were presented, one for each of four vehicles being supervised, along with overlaid symbology providing vehicle specific information. Interactions with the symbology could be made to manage vehicle systems (e.g., return a vehicle to base for refueling) and manage missions (e.g., pulling bar representing new mission down to a specific vehicle's bar to make the corresponding mission-vehicle assignment).

A human-in-the-loop simulation evaluation was conducted to determine if the addition of this prototype temporal display improves supervisory control performance. Participants completed experimental trials with and without the temporal interface. For trials without the temporal interface, participants completed steps via multiple windows, mainly via interactions with symbology overlaid on the map. Participants were required to complete multiple types of tasks representative of the tasks envisioned for multi-vehicle supervisory control. For all tasks, response time and accuracy measures were recorded. The results showed that performance was better for all task types when the temporal interface was present (results significant for eight of twelve task types). Not only was performance better for tasks involving interactions with the temporal interface, but also for secondary tasks involving peripheral windows. This finding suggests that the temporal interface helped reduce overall workload and improve situation awareness, such that more attention could be devoted to other tasks. Subjective data were aligned with the performance data. Documentation of the results is underway.

3.2.3 Prototype Temporal Interface for Multiple Vehicles Coordinating on Time-sensitive Target Prosecution

While both the performance and subjective results were favorable in the evaluation of the temporal interface described above, the surveillance missions represented in the experimental trials were not especially complex in that each was performed by a single vehicle and there were few temporal constraints. It was decided to next design a temporal interface that could support multiple vehicles that coordinated actions with respect to time-critical targeting tasks. In this regard, a supporting use-case scenario was identified, as well as the design of display elements and control functionality for the novel interface (Figure 4). It was determined that a task-centric temporal format, rather than a vehicle-centric format (Figure 3) was more appropriate for the time-critical tasks that involved multiple steps for each target, including both sensor-equipped vehicles and weapon-equipped vehicles. Each horizontal line presented information related to one target that required imaging and prosecution before a deadline. To support the selection of vehicle resources and appropriate allocation of attention across the tasks, several different levels of automated aids were also instantiated. In one lower level of automation, deadlines for the overall target task, as well as when the image of the target would expire, were indicated with symbology. In a higher level of automation, additional symbology (including colored zones overlaying the timeline) was presented to show recommended deadlines for subtasks in the target prosecution cycle as well. A third level provided an additional decision aid, highlighting which of multiple vehicles the automation recommended that the operator should select for the current targeting task. The design also featured novel "glyphs" in which individual dimensions (variables) are mapped, in real-time, to

attributes of a graphical shape or symbol. These dynamic information-packed symbols are designed to conserve display space and reduce the operator's need to visually scan and integrate information across the control station. For this prototype, different glyphs are used to denote progress on the time-sensitive target tasking as well as the status of the different UAS types (e.g., sensor and weapon). Research examining this new prototype was initiated, but not completed in the reportable timeframe of this report.

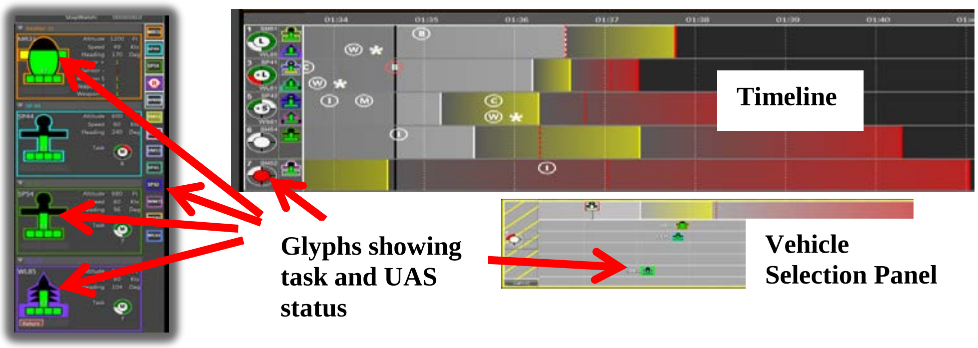

Figure 4. Prototype Timeline Interface Windows Integrated into Vigilant Spirit Control Station to Support Multiple Vehicles Coordinated on Time-sensitive Target Prosecution

3.2.4 Operator-Automation Interface Design Inspired by Finite State Automata Graphs

Besides the efforts described above that focused on a timeline interface that has both display and control functionality, another design/development effort supported used a different approach for providing the operator with a display that supports "at-a-glance" understanding of the current state of all vehicles and missions being managed. This approach, termed "L-PRISM" (Layered Pattern Recognizable Interface for State Machines), is based on a Finite State Automata Graphical technique (see Figure 5). The larger display elements in the display window represent major "operational states"—segments of a mission being performed by multiple UASs, along with automated sensing ground sensors. Symbology (icons and/or alphanumeric text) within each major display element indicates the vehicles currently performing tasks related to that mission "state." Thus, with a quick glance across the display elements, the operator can identify the mission states and vehicle/sensor taskings from the template. Moreover, the temporal relationships (past, present, future) between the various states can be depicted, as well as cues of task/state transitions. This use of pattern recognition to depict the relationships of the different entities may enhance operator's situation awareness, especially when highly automated collaborating systems can have autonomous decision making capabilities within a decentralized control architecture. For such applications, it is even more critical that the functionality of the automation is transparent as the operator may only have limited visibility and control of certain entities. The L-PRISM design also provides means for the operator to manipulate multi-vehicle goals, tasks, and constraints with less point and click menu navigation.

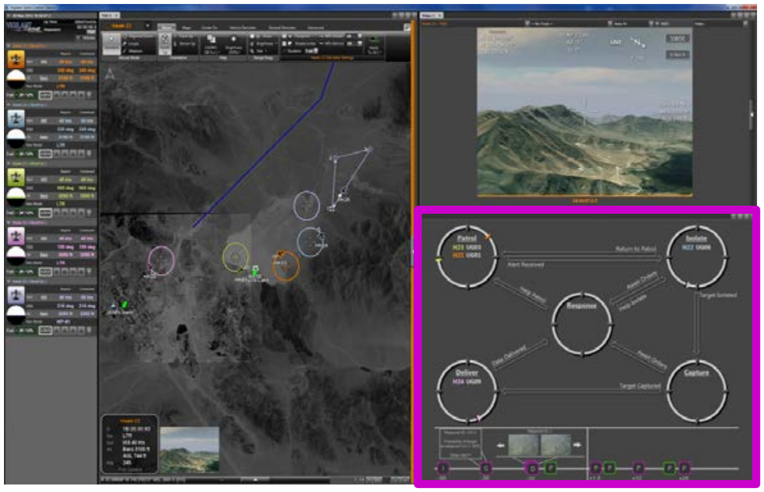

Figure 5. Illustration of L-PRISM prototype:
Layered-Pattern Recognizable Interfaces for State Machines

This includes a pictographic temporal tool below the larger window that provides a mechanism for the operator to store, recall, and view imagery and other information packets transmitted from air and ground entities. The effort to date has involved design of the display interface and instantiation of the interface in Vigilant Spirit Control Station software (Reference 24). Support has also been provided in preparations underway to evaluate the interface in simulations and actual live tests. This effort is part of a larger Collaborative Systems Control Strategic Technology Thrust multi-AFRL Technical Directorate Initiative called "Value of Information in Collaborative Systems."

3.3 Other Projects

One effort involved personnel with OR Concepts Applied, the firm that designed the initial version of the ALOA simulation via an earlier Small Business Innovative Research effort. Several features of the test simulation were improved and expanded to increase the functionality and usability of the simulation to explore the balance of autonomy with operator involvement.

Personnel from Alion Science & Technology conducted another effort. Several gaming technologies were evaluated to identify display and control concepts that might be useful for application in the control of UASs. Gaming technologies evaluated ranged from massively multiplayer online role-playing games to arcade-style games. While this assessment identified potential research areas, the similarities among many games, and the shortage of games that address some of the key problems with unmanned systems (mainly switching between the supervisory role and the direct control role), made this effort less fruitful than originally anticipated. A probable reason relates to the differing primary goals of games and real UAS control. Games are designed to maximize the user's sense of engagement, rather than providing the most efficient means for accomplishing a given mission. Hence, enhancing mission performance,

while reducing operator workload is not a goal in games. This and other fundamental differences complicate translating successful concepts from one domain to another. There were two publications documenting this work: a technical report and a conference paper (References 25 and 26, respectively).

4. SUMMARY

This report provides a summary of research conducted by the Supervisory Control and Cognition Branch (RHCI) of the 711th Human Performance Wing of the Air Force Research Laboratory that examines the balance of autonomy with operator involvement. Efforts during this reporting period also involved the design and evaluation of novel operator-automation interfaces. Continuation of this research will be summarized in the final report for Task Order 49, performed in support of the Warfighter Interface Research & Technology Operations (WIRTO) contract (FA8650-08-D-6801).

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6. LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AFRL	Air Force Research Laboratory
ALOA	Adaptive Levels of Autonomy
BATC	Ball Aerospace & Technologies Corporation
FLEX-IT	Flexible Levels of Execution – Interface Technologies
LOA	Level of Automation
L-PRISM	Layered Pattern Recognizable Interface for State Machines
RHCI	Supervisory Control and Cognition Branch, Warfighter Interface Division, Air Force Research Laboratory, Human Effective Directorate, 711th Human Performance Wing
UAV	Unmanned air vehicle
UAS	Unmanned air vehicle system
WIRTO	Warfighter Interface Research & Technology Operations